

ECCOMAS Thematic Conference

VIII International Conference on Computational Methods in Marine Engineering



# MARINE 2019

Göteborg, Sweden, 13-15 May 2019

IACM Special Interest Conference

## Fatigue Simulation of a fibre-glass ship

Joel Jurado Granados

Invited Session: Lightweight Composite Materials in Shipbuilding

Göteborg, 13<sup>th</sup> May 2019

## BRIEF DESCRIPTION & OBJECTIVES

FIBRESHIP3  
INTEGRAL COMPOSITE SHIP

- **Formulation:**
  - FATIGUE DAMAGE MODEL.
- Adaptation of fatigue formulation to composites.
- Validation of the methodology proposed.
  - Two different composite systems: SANDIA & KAWAI TESTS.
- **RESULTS & CONCLUSIONS**
  - Failure modes and load-position graphs.

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- **OBJECTIVES**
  - Apply the fatigue formulation developed to complex composite structure with multi-axial loads.
  - Analyze the fatigue performance of the structure, identifying which plies are more prompt to fail, as well as the failure mode.
  - Study the potential capabilities of the formulation and methods introduced.

## TASK: Fatigue performance of composites

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INTEGRAL COMPOSITE SHIP

### INTRODUCTION. Fatigue phenomenon

ASTM E1823 standard: "The process of permanent, progressive and localized structural change which occurs to a material point subjected to strains and stresses of variable amplitudes which produces cracks which lead to total failure after a certain number of cycles".



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Importance of the fatigue in naval structures. Prove of it is the existence of specific rules on Class Societies

DNV-RP-C203



ShipRight FDA



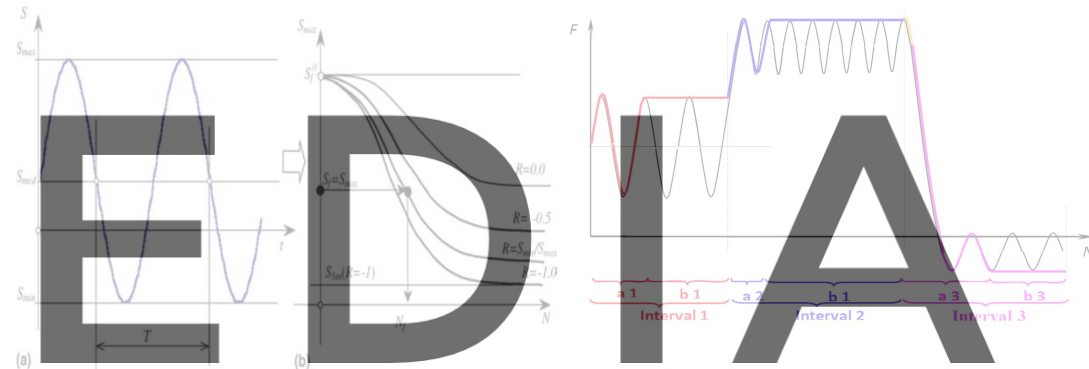
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# FATIGUE FORMULATION

- Fatigue damage formulation initially developed for metallic materials.
- The constitutive law is modified by means of a reduction function, to account for the cyclic behaviour of the load: **phenomenological model (stiffness and strength degradation)**.
- Forward advanced strategy  $\rightarrow$  stabilization norm

$$\eta = \sum \frac{R^k - R^{k-1}}{R^k}$$



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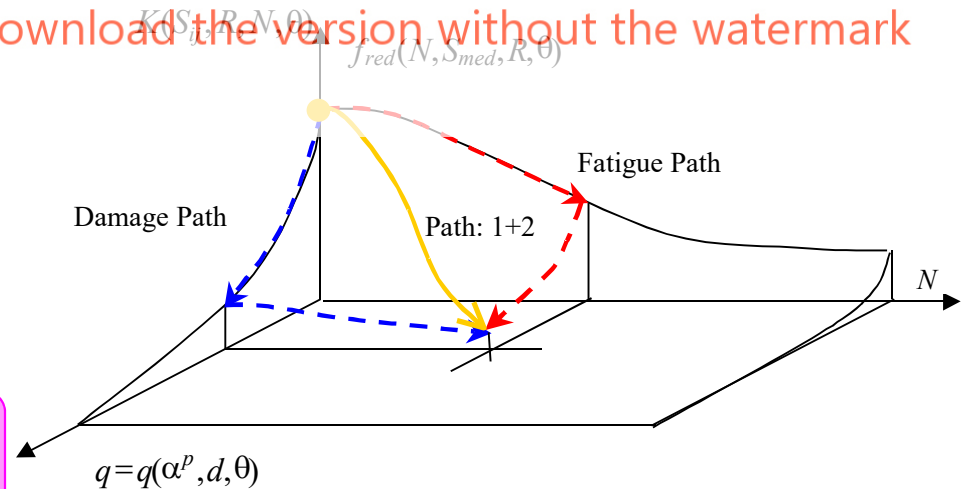
- The formulation can take into account different block loading sequence.
- Material parameters of  $f_{red}$  are obtained by means of experimental S/N of the materials.

Non-fatigue constitutive equation:  $f(\sigma) - K(\sigma_{th}) \leq 0$

Fatigue application:  $f(\sigma) - f_N(N, \sigma_m, R) \cdot K(\sigma_{th}) \leq 0$

Influence of  $N_c$  strength reduction (HCF)

Influence of *Quasi-Static* strength reduction.



# ADAPTATION OF FATIGUE FORMULATION TO COMPOSITES



UD loaded at longitudinal direction has a fibre-dominated performance.

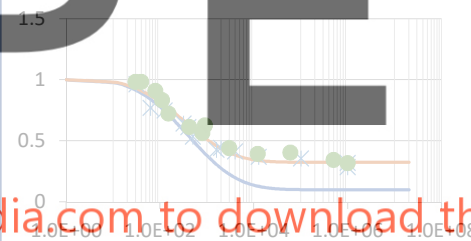
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UD loaded at transverse direction has a matrix-dominated performance.

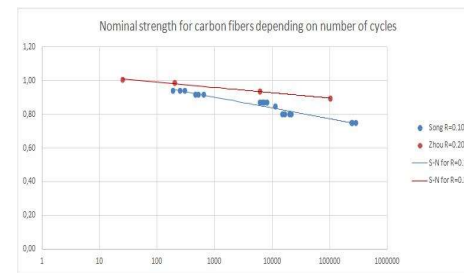


## FATIGUE MODELS

UD 90 S/N normalized



UD 0 S/N normalized



Fatigue constitutive law for matrix

Fatigue constitutive law for fibers

SP MIXING THEORY

Fatigue models coupling

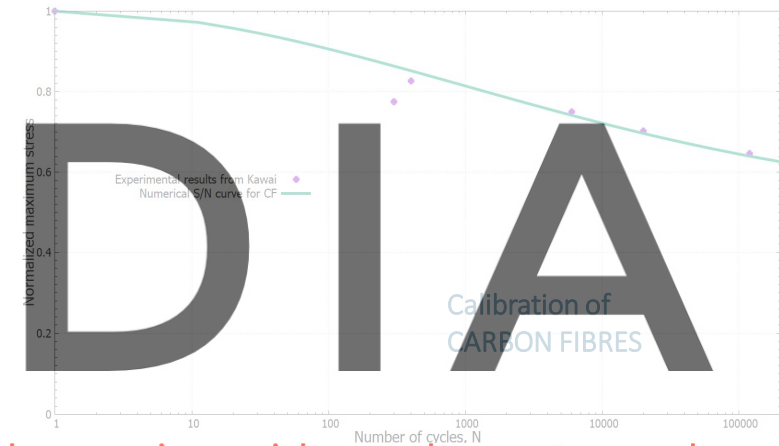
Composite laminate fatigue performance



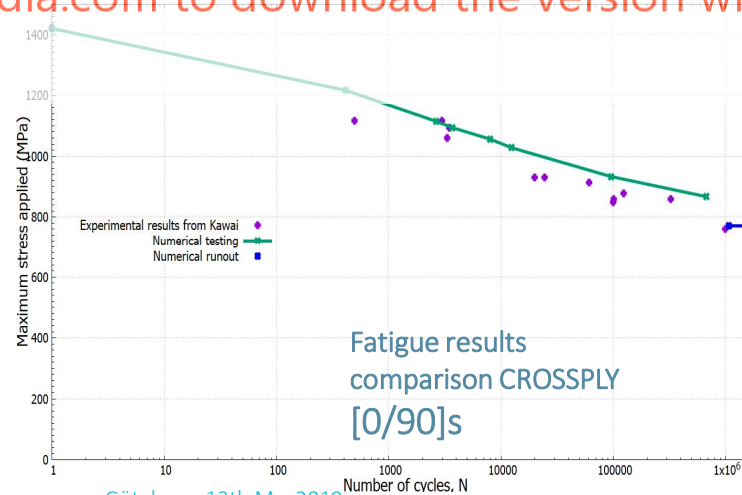
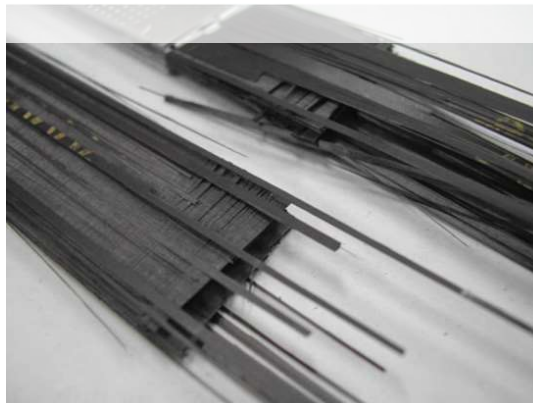
# VALIDATION OF THE FORMULATION APPLIED TO COMPOSITES

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INTERNAL COMPOSITE SHIP

## Carbon/Epoxy system. Kawai



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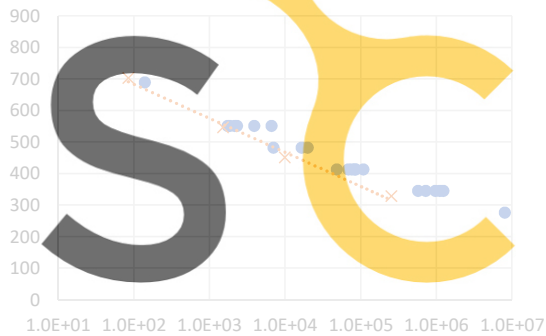
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# VALIDATION OF THE FORMULATION APPLIED TO COMPOSITES

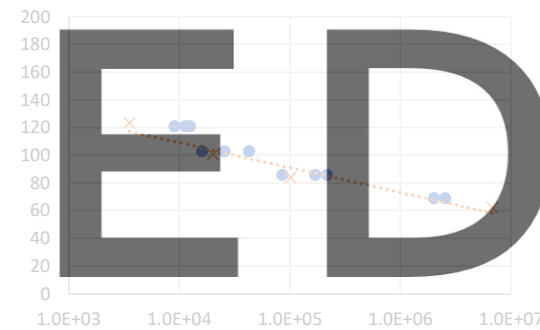
FIBRESHIP3  
INTEGRAL COMPOSITE SHIP

## Glass/Polyester system. Sandia

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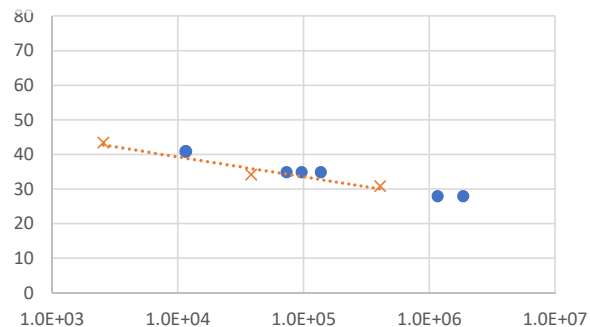


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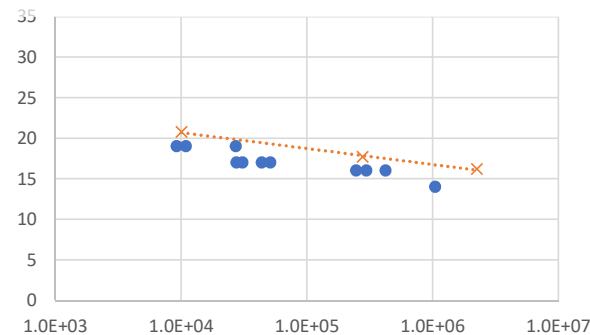


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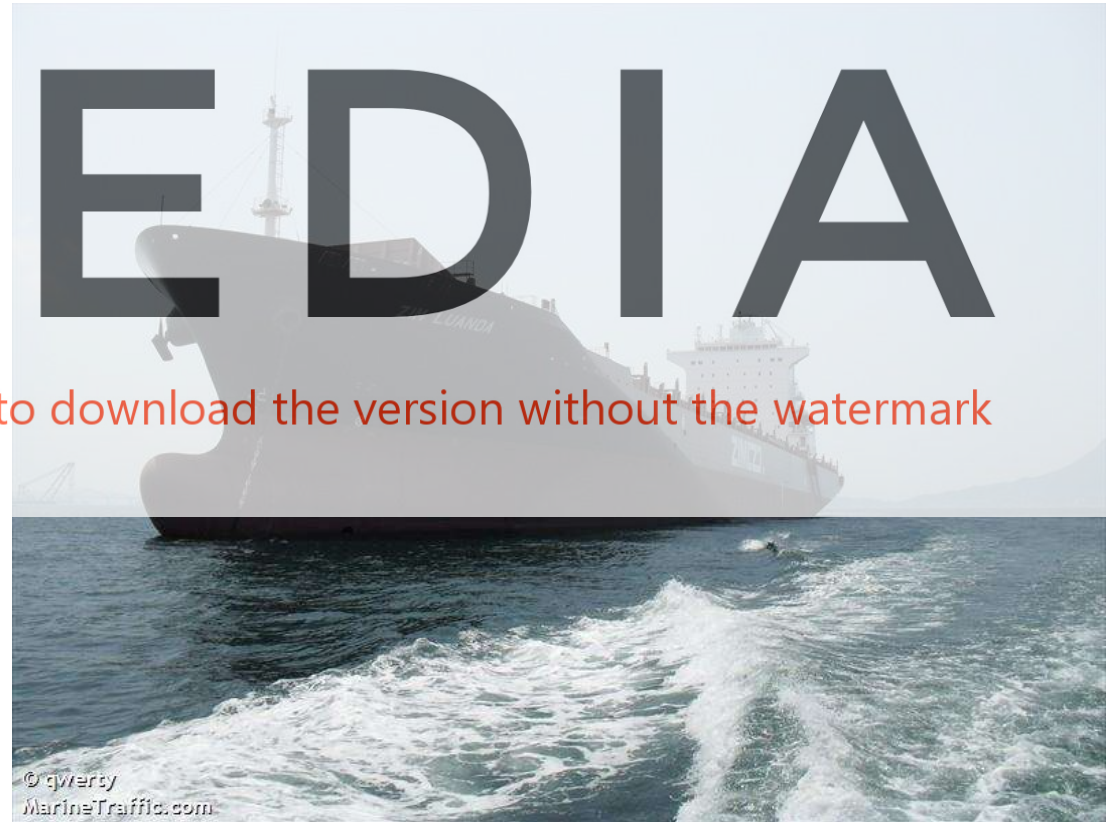


## PREFACE

- Container ship has been used as one of the fibre-ships to design.
- From a Steel Ship to a Composite Ship. New architecture, new scantlings, new behavior.

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- From an existing steel ship, the loads applied to the structure are obtained. These loads will be applied as boundary conditions to the composite vessel.





# FATIGUE SIMULATION OF A SHIP-SUB-STRUCTURE. From Steel to Composite

FIBRESHIP3  
INTEGRAL COMPOSITE SHIP

Zone to  
study

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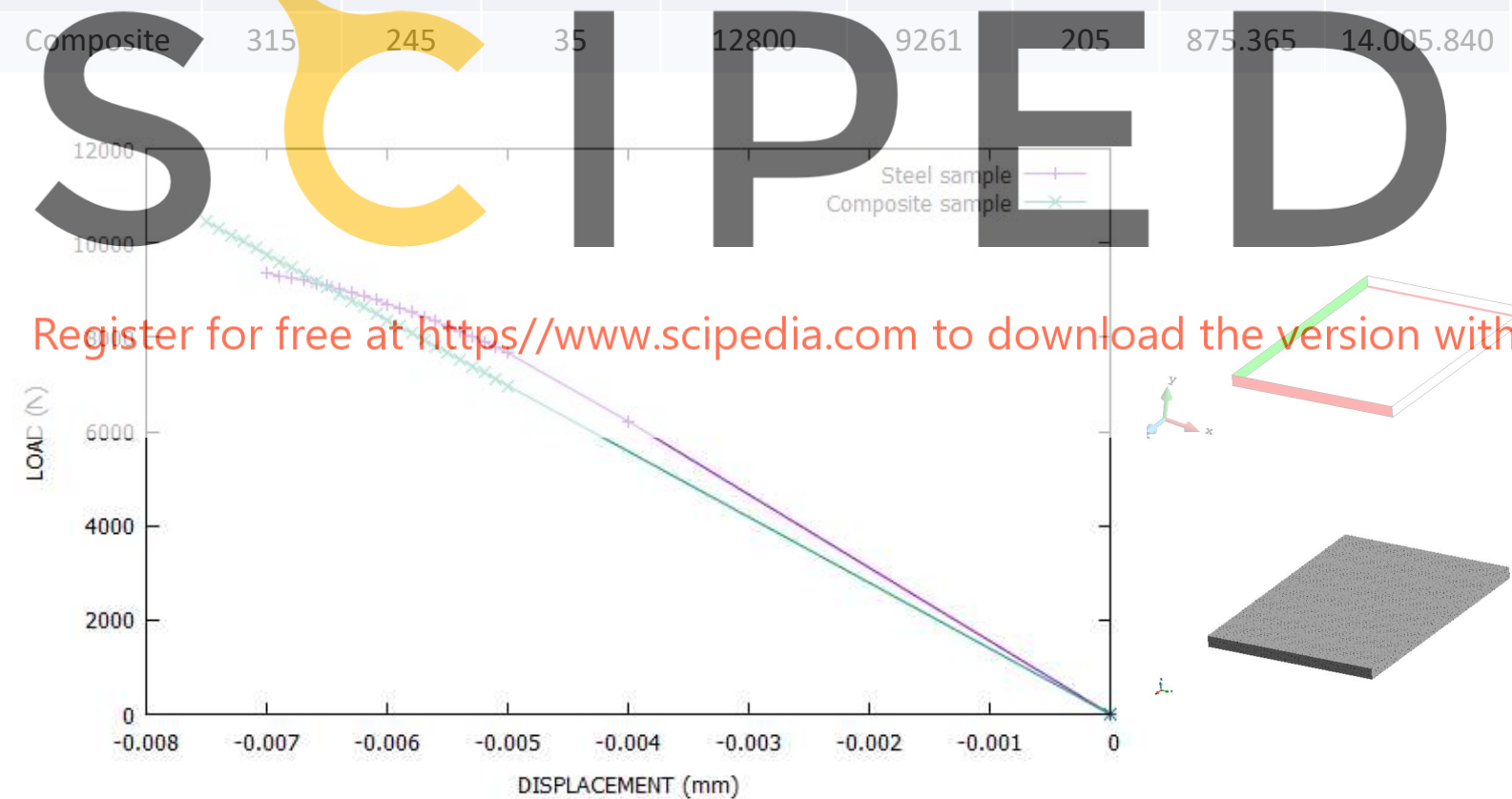


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## FATIGUE SIMULATION OF A SHIP SUB-STRUCTURE. Equivalent material

**FIBRESHIP3**  
INTEGRAL COMPOSITE SHIP

Material	Length (mm)	Width (mm)	Thickness (mm)	Nº elements	Nº nodes	E (GPa)	I (mm <sup>4</sup> )	E*I
Steel	315	245	15	25600	21609	16	68.906	14.124.500
Composite	315	245	35	12800	9261	205	875.365	14.005.840

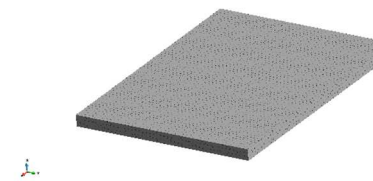
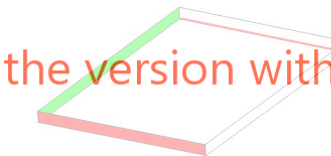


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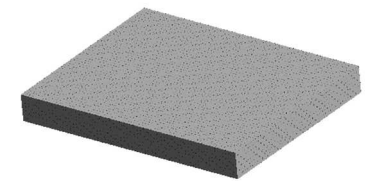
Quasi-isotropic laminate:  
[0/90/-45/+45]<sub>s</sub>

Structured mesh  
Linear hexahedral  
elements

Size = 5mm

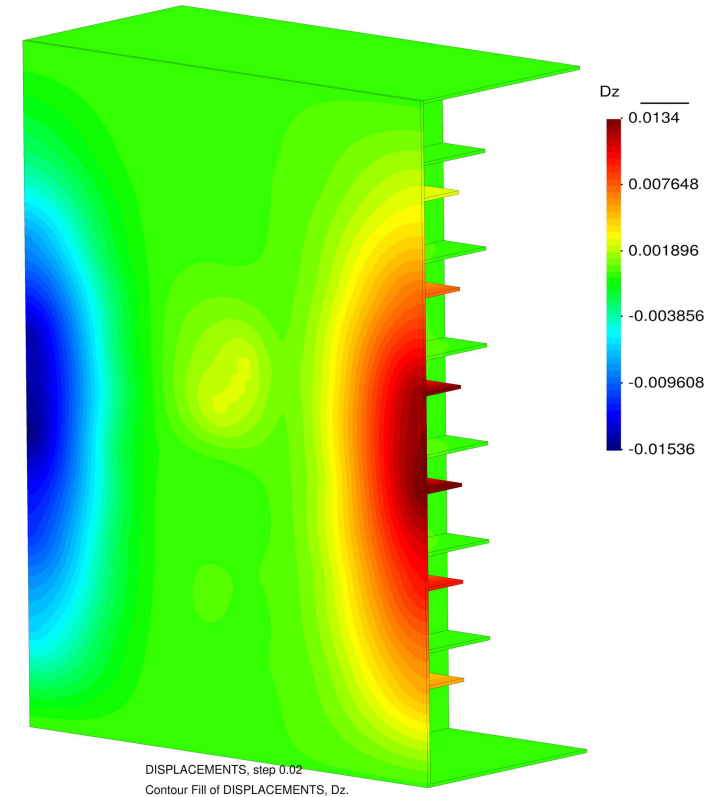
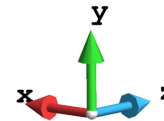
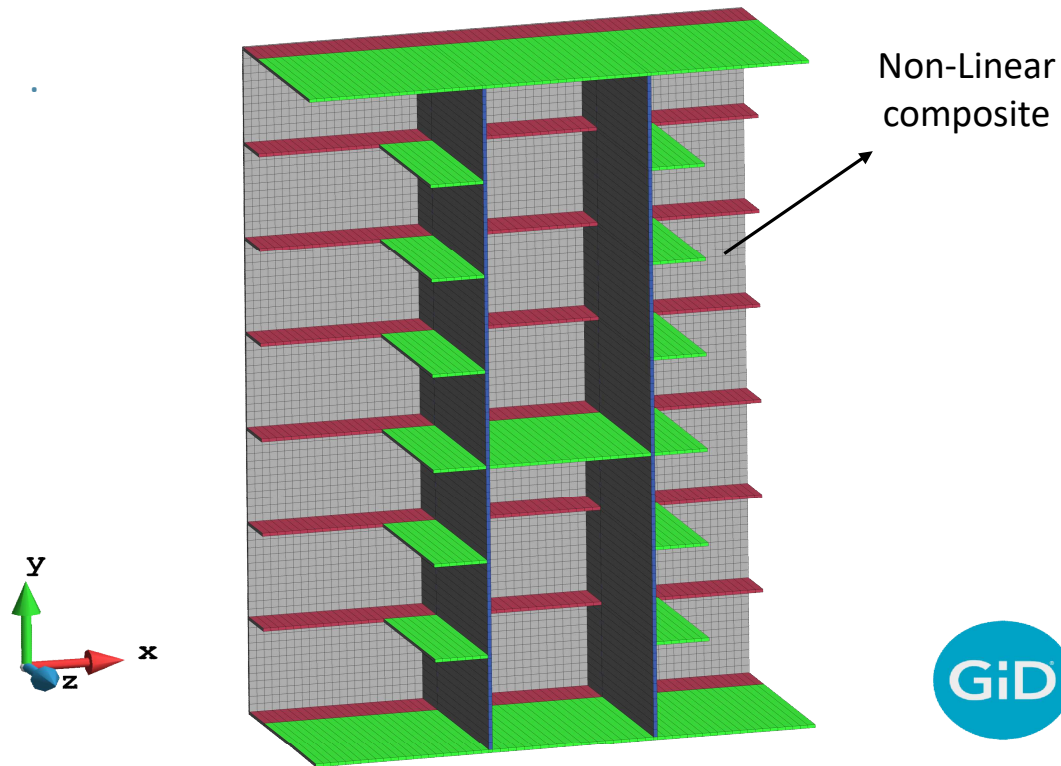


D  
X



# FATIGUE SIMULATION OF A SHIP SUB-STRUCTURE.

**FIBRESHIP3**  
INTEGRAL COMPOSITE SHIP



Nº elements	Nº nodes	Element type	Element size
25600	21609	Linear hexahedral	35 mm

## Scenarios – First attempts

SCENARIO 1
-Stress ratio $R=-1.0$ -Jumps = 25.000 cycles -Maximum load level = 1.0

SCENARIO 2
-Stress ratio $R=-1.0$ -Jumps = 75.000 cycles -Maximum load level = 1.5

SCENARIO 3
-Stress ratio $R=0.10$ -Jumps = 50.000 cycles -Maximum load level = 1.6

Identify which cases are lead to fatigue failure and which process is it.

## FATIGUE SIMULATION OF A SHIP SUB-STRUCTURE. Results

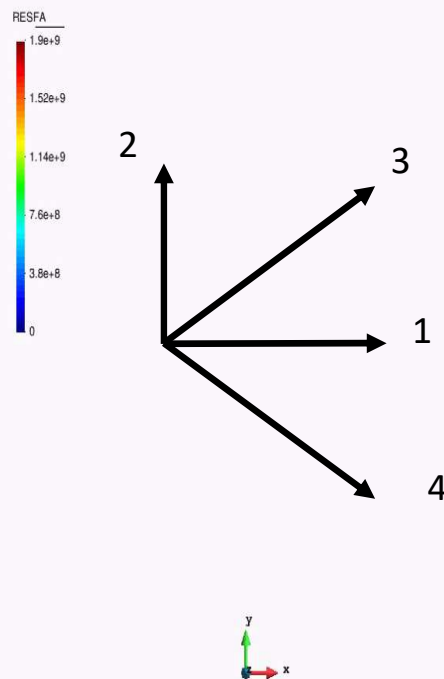
### WORST: SCENARIO 2

Cycle jumps: 1, 25.000, 150.000, 225.000 cycles.

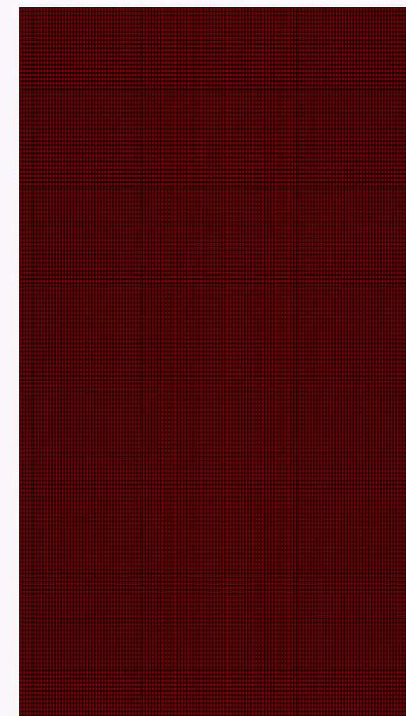
Strength  
reduction  
Glass 2



step 1  
Contour Fill of Int.Var://Composite1//Layer03//EGlass//RESFA.



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step 1  
Contour Fill of Int.Var://Composite1//Layer01//EGlass//RESFA.

Strength  
reduction  
Glass 1

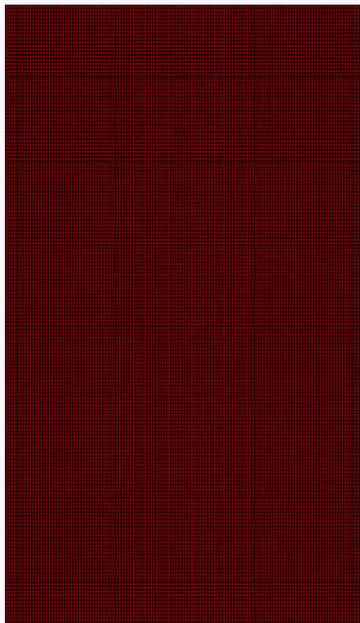


## FATIGUE SIMULATION OF A SHIP SUB-STRUCTURE. Results

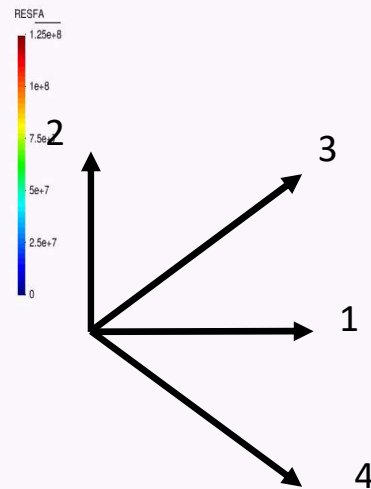
### WORST: SCENARIO 2

Cycle jumps: 1, 25.000, 150.000, 225.000 cycles.

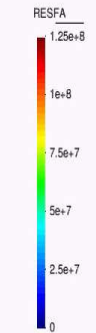
Strength  
reduction  
Polyester 2



step 1  
Contour Fill of Int.Var.//Composite1//Layer03//Polyester//RESFA.



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Strength  
reduction  
Polyester 1

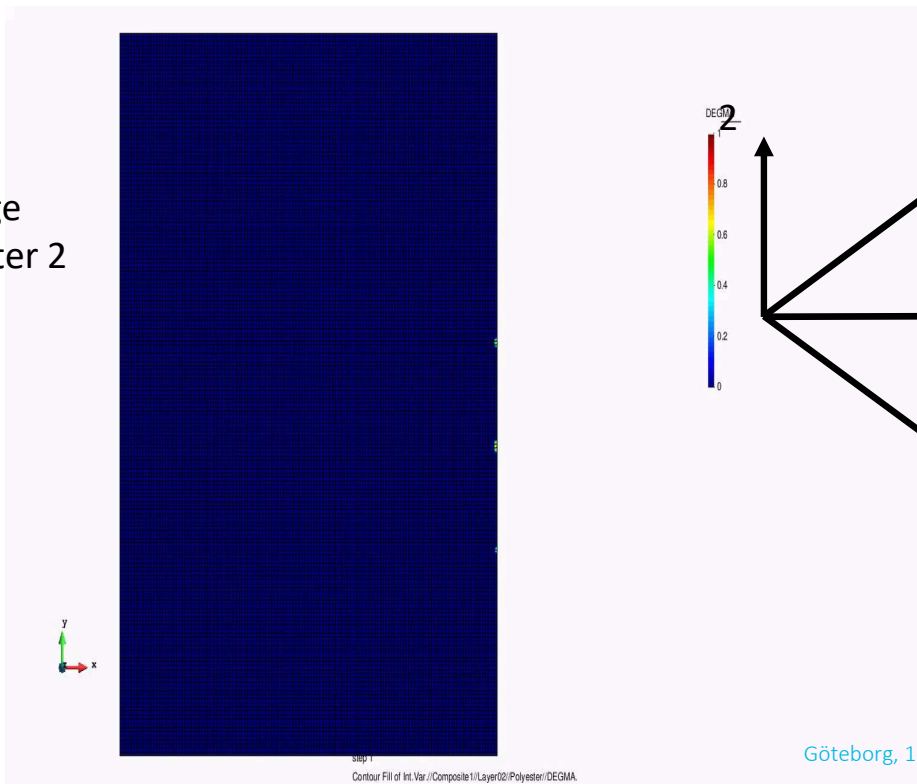
step 1  
Contour Fill of Int.Var.//Composite1//Layer01//Polyester//RESFA.

## FATIGUE SIMULATION OF A SHIP SUB-STRUCTURE. Results

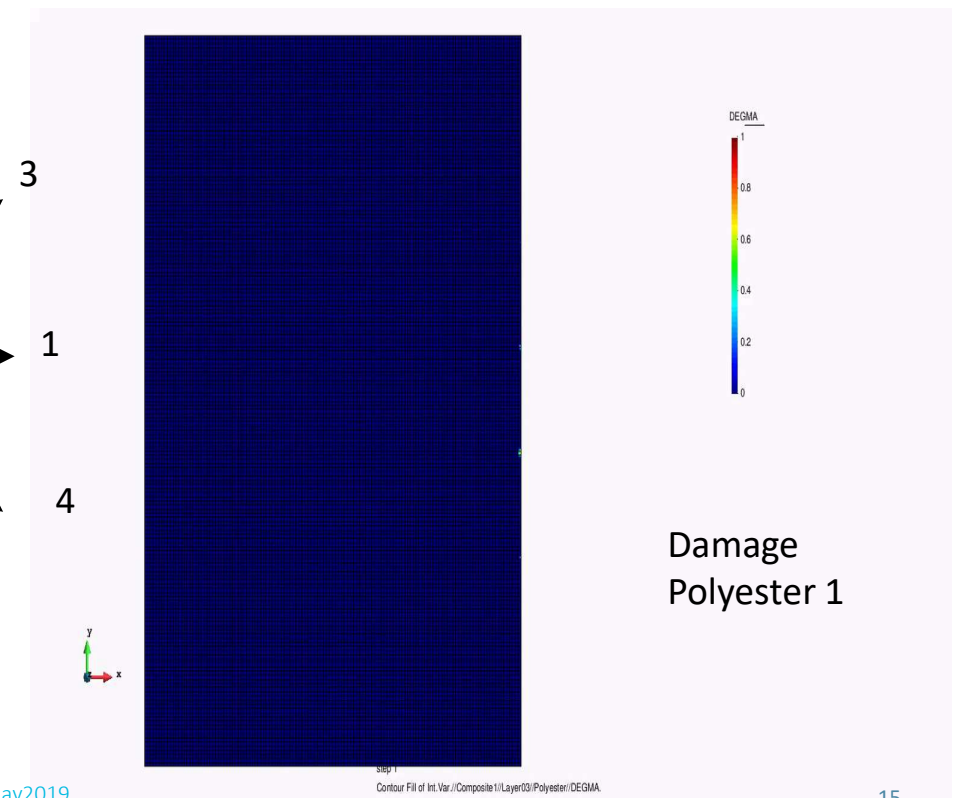
### WORST: SCENARIO 2

Cycle jumps: 1, 25.000, 150.000, 225.000 cycles.

Damage  
Polyester 2



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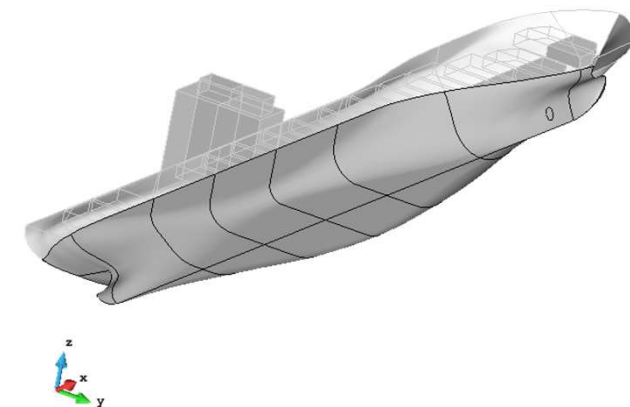
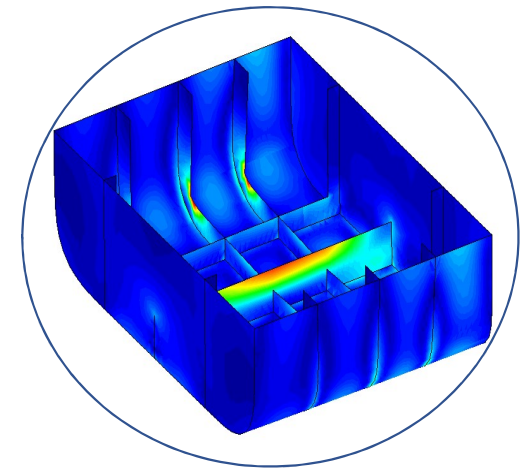


Damage  
Polyester 1

## CONCLUSIONS, RELEVANT ASPECTS AND FURTHER WORK

**FIBRESHIP3**  
FIBER REINFORCED SHIP

- A methodology has been conducted to adapt the existing fatigue formulation to composites.
- The methodology has been tested with success in two different composite systems and different configurations.
- The formulation is able to follow the fatigue degradation of constituent materials, obtaining the fatigue life of the structure.
- Fiber are not prompt to suffer fatigue → High stiffness requirements means higher scantlings → Lower stresses.
- 50% of loose of matrix strength! → Delamination and matrix cracking.
- Adapt the current formulation and methodology to 2D elements → Computationally expensive.
- One step beyond → Fatigue study of structural details.



**FIBRESHIP3**  
INTEGRAL COMPOSITE SHIP



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**THANK YOU**



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